NAVAL HEALTH RESEARCH CENTER

A SIMULATION PROGRAM TO PROJECT

CASUALTY AND ILLNESS RATES

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SUMMARY

Problem

Modeling of medical resource requirements during military operations requires accurate projections of disease and non-battle injury (DNBI), wounded-in-action (WIA), and killed-in-action (KIA) rates.

Objective

A ground casualty projection system (FORECAS) has been developed. This paper documents FORECAS in terms of a guide to its use, and in terms of the underlying statistics.

Approach

Casualty data were extracted for troops serving during the Vietnam War, the Korean Conflict, the Okinawa operation during World War II and the Falklands. The statistical distributions of DNBI, WIA and KIA incidence for both combat and combat support troops were analyzed separately. This information was than used to determine the appropriate statistical distributions to be used in the simulation program.

Results

The FORECAS casualty projection system simulates casualty and illness arrival rates under different user-defined battle scenarios. Output of the simulated data reflects the nuances of the actual historical data.

Conclusions

Assessment of the statistical distributions of the daily disease and casualty incidence allows accurate simulation of different theater medical situations. The stochastic nature of a battle situation is demonstrated with the use of line graphs and summarized statistics.

A Simulation Program to Project
Casualty and Illness Rates

Forecasts of the expected injury and illness incidence in a combat theater are critical to the medical resource planning of a military operation. Distribution characteristics of casualty incidence patterns may be derived by fitting theoretical distributions to historical casualty data. These distribution characteristics can then provide a basis for simulating future WIA (wounded in action), KIA (killed in action), and disease and non-battle injury (DNBI) rates.

A ground casualty projection system (FORECAS) has been developed. The purpose of the FORECAS software is threefold: 1) to provide medical planners with estimates of the average daily rates of casualties that may be sustained in a given scenario, 2) to indicate the maximum daily casualty loads that may be incurred and for which planning is necessary, and 3) to enhance understanding of the statistical properties of DNBI, WIA, and KIA rates for use in future modeling efforts. The utility of FORECAS as a planning tool goes beyond projecting average daily DNBI and WIA admission rates for operations--admission rates that are necessary input to various Department of Defense medical resource models[1,2]; FORECAS also reflects the "pulse and pause" nature of combat operations in the interarrival times and the magnitudes of projected casualty frequencies. By displaying the dispersion, range, and other statistical properties of casualty and illness data, FORECAS graphically depicts the potential patient flows within a theater of operations--information that is critical to optimal medical resource allocation.

Development of a casualty simulation model required the analysis of historical data to determine the appropriate probability distributions. Studies performed at the Naval Health Research Center[3,4] found that DNBI rates among combat support troops follow a simple Poisson process that can be approximated by a normal distribution. Among combat troops, however, greater fluctuations in DNBI rates are evidenced, and this process is best represented by a lognormal distribution. Rates of WIA are characterized by a nonstationary Poisson process combined with the appropriate time series attributes. Further, a significant amount of autocorrelation was found within both the DNBI time series data and the WIA

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data. Killed-in-action rates can be depicted as a lesser function of WIA.

Another significant aspect of the empirical rate analysis was the degree of cross correlation between the WIA and the DNBI time series data. The cross correlations of WIA and DNBI incidence, as well as the aforementioned autocorrelations, both gained in strength with increases in battle intensity. Support troops DNBI data, in contrast, is a simple random variable that is independently and identically distributed.

The present report provides user documentation for the FORECAS ground casualty projection system. Part I is a guide to usage of this planning tool. Part II describes the statistical underpinnings of the casualty projection system.

PART I -- USE OF THE FORECAS PROJECTION SYSTEM

FORECAS System minimum requirements

- an IBM or IBM-compatible PC
- an EGA to SVGA monitor
- 640k of base memory
- 500k disk space
- serial mouse

Setup

FORECAS is distributed as a stand alone executable (.exe) file. The program runs faster and more efficiently from the hard drive as opposed to the floppy disk. The file runs straight from a DOS prompt. Installation is accomplished by inserting the 3.5" disk into the drive and typing:

x:\install.

This starts a DOS batch file that makes a directory called "FORECAS". It also copies the necessary files and places them in the new directory. To start the program simply go to the "FORECAS" directory and at the DOS prompt type in: "forecas".

The program operates with the use of the left-side mouse button and the carriage return (Enter key). The left-hand side button on the mouse is used to input selections while the Enter key is used to progress from screen to screen. The introductory screen prompts the

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user to press the Enter key to precede to the input screens.

The first input screen employs a graphical user interface to prompt the user for the information needed for the simulations. This screen displays the following options regarding the illness or injury incidence to be projected: DNBI, WIA, KIA, DNBI & WIA, and WIA & KIA. This screen is shown as follows:
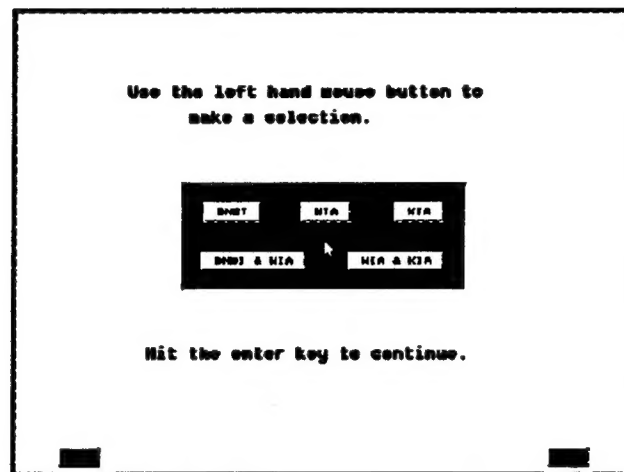
Upon selection of the type of incidence to be projected, as with all input screens, a bell sounds indicating that the projection system has registered an input. The user may select only one option at a time. Selection of a second incidence projection option will override the user's first choice. If the user makes no selections and tries to proceed to the next screen a warning screen will come up asking the user to either make a selection or exit. There is an EXIT button at the lower right hand side of the screen. Selecting the EXIT button with the left-side mouse button returns the user to the operating system. There is also a HELP button at the bottom left hand side corner of the screen where additional information may be obtained with the use of the left-side mouse button. Proceeding to the next screen is accomplished by using the Enter key.

The second input screen prompts the user for information pertaining to battle tempo. Again, the user makes inputs with the use of the left-side mouse button. This screen requests the user for data on the degree of battle intensity of the proposed battle scenario. The combat intensity options are: NONE, LIGHT, MODERATE, HEAVY, and INTENSE. The screen is shown below:

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Use the mouse to select an intensity

Hit the enter key to continue.
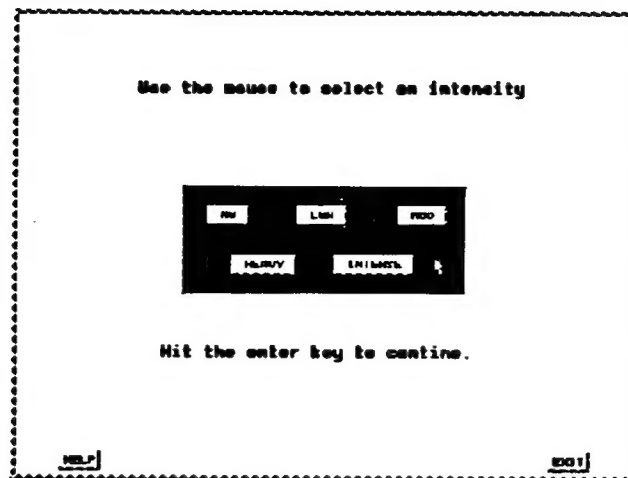
The NONE category represents a "no combat" situation; though tensions may exist, no combat is taking place (e.g.,an occupying force). While DNBI arrivals will still occur in this situation, there will be no WIA or KIA. If the user has chosen either WIA, KIA, or a combination of the two a prompt will later appear indicating that there are no wounded or killed soldiers when there is no military confrontation. The other battle tempo options reflect the magnitude of injury and illness incidence evidenced in previous combat operations of varying intensities[5,6]. The user is required to select a single battle tempo option. Selection of a second or successive intensity option will supplant the previous battle tempo input. Again, there are HELP and EXIT buttons in the bottom left and right corners, respectively. These are activated with the use of the left-side mouse button. After selecting a battle intensity option, the user proceeds to the next screen by pressing the Enter key.

The next input screen allows the user to specify the numbers and types of troops for the projected scenario. There are three categories of troops: INFANTRY, SUPPORT, and SERVICE SUPPORT. The screen is shown as follows:

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Use the mouse to choose a troop selection and troop strength.

INFANTRY	SUPPORT	SERVSUP
5,000	5,000	5,000
7,500	7,500	7,500
10,000	10,000	10,000
12,500	12,500	12,500
15,000	15,000	15,000
17,500	17,500	17,500
20,000	20,000	20,000
25,000	25,000	25,000
30,000	30,000	30,000
40,000	40,000	40,000
50,000	50,000	50,000

HELP   Use the enter key to continue.   EXIT

Combat troops refer to infantry personnel; Support troops represent intradivisional support such as tank, artillery, light-armored infantry, and combat engineer units; Service Support personnel includes the Force Service Support Group (FSSG) and the Surveillance, Reconnaisance, Intelligence Group (SRIG). Below each of the three troop categories are buttons for specifying the number deployed of that troop type . The user must select at least one troop type and indicate the strength of that force. Selection of a subsequent troop strength within an already-selected troop category supersedes the previous strength input.

The next input screen prompts the user for two parameters regarding the operational theater and length of the proposed scenario. On the left side of the screen are three choices for geographic location: EUROPE, EAST ASIA, SOUTHWEST ASIA. On the right side of the screen there are options for the length of the operation: 15 DAYS, 30 DAYS, 60 DAYS, 90 DAYS, and 120 DAYS. The input screen is shown as follows:
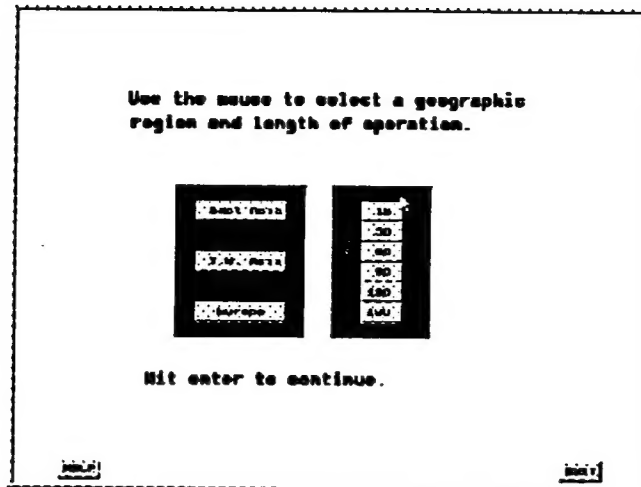
The user makes these selections with the use of the left-side mouse button. The user must choose a geographical theater option and specify the length of the operation. As with the other input screens, the last button that is selected is the option that will be implemented.

Upon choosing the right-side mouse button, simulation results are graphically presented. The graphical presentations consist of WIA, DNBI, and KIA incidence line charts plotted across the temporal course of the simulated scenario. Initially, each graph depicts a single troop type. If the user has selected more than one troop type, there will be a graph for each troop category followed by a composite line chart across all troops categories.

Each arrival stream (DNBI, WIA, KIA) is depicted in different colors to enhance user viewing. Along the y (vertical) axis the scale shows the magnitude of the arrivals, while the x (horizontal) axis represents the temporal course of the operation. A short bell signals the end with each arrival stream. After viewing the graph, the user then presses the Enter key to advance to the next screen. The user may return to the operating system at this point by selecting the Escape key.

A statistical summary screen follows each graphical depiction of injury/illness incidence. The user-defined parameters are shown at the top of the screen. Below these parameters are descriptive statistics representing the casualty flow over the operation. If the user opted for KIA projections, summary data on total KIA, average KIA, maximum daily KIA, and daily KIA rate per 1,000 troop strength is presented. If the user has selected DNBI‬ or WIA incidence, the output shows:

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-TOTAL NUMBER OF PRESENTATIONS

-TOTAL NUMBER OF ADMISSIONS

      -Total number of diseases*

      -Total number of non-battle injuries*

      -Total number of battle fatigue cases*

-DAILY ADMISSION AVERAGES

-MAXIMUM ADMISSIONS ON A SINGLE DAY

-AVERAGE RATE PER 1,000 STRENGTH PER DAY

-MAXIMUM DAILY RATE PER 1,000 TROOPS

-MINIMUM DAILY RATE PER 1,000 TROOPS

Presentations represent the total patients expected to be seen at Echelon II and III treatment facilities combined; admissions represent only those patients expected to require Echelon III treatment. Upon depressing the Enter key, the system then proceeds to the next graphical presentation (line chart for the next troop category). This process repeats itself until all troop categories have been viewed or the user quits. After all the graphs and statistical summary screens have been viewed, the user is returned to the initial input screen to create another scenario or to quit the program.

PART II -- STATISTICAL UNDERPINNINGS OF FORECAS

For the simulation to be adaptable to future operations of varying sizes, the output first required adjustment to a generic troop strength that can be applied to different troop strength levels. The historical data that were analyzed to form the basis for the simulation come from Marine company and battalion unit diaries[3]. These units were of varying strengths, consequently illnesses and injuries were computed per 1,000 troop strength per day. This standardization of the data gives the output a uniform perspective, which can be easily adjusted across various troop strength levels.

The simulation is accomplished with the aid of a uniform random number generator to

start each of the rates. Separate generators are used for each of the arrival rates[7,8,9].

DNBI Rates

The simulation of support troop DNBI rates makes use of variates drawn from a normal distribution. The normal distribution is used to approximate a Poisson process that best represents the historical data in large sample sizes. The user has the option of specifying a small sample size (15 days) so care should be taken in assuming that this is an accurate approximation to a Poisson process. The variates Y are distributed as:

$$Y \sim N(\mu, \sigma^2)$$

Generation of the combat troop DNBI can be derived from a lognormal approximation to a Poisson process. The variates from a lognormal distribution are distributed as:

$$X \sim LN(\mu, \sigma^2)$$

Generation of this variate is similar to the normal distribution. After deriving Y, the normal variate, we generate X the lognormal variate:

$$X = e^Y$$

This results in an IID lognormal variate. This is entered into the equation:

$$X_t = \beta_0 + \beta_1 X_{t-1} + \beta_2 W_t + LN(\mu, \sigma^2)$$

where:

X_t = the Combat DNBI variate with the necessary auto and cross-correlations.

β_i = constants used to obtain the necessary auto and cross-correlations.

W_t = the WIA variate.

$LN(\mu, \sigma^2)$ = the IID lognormal variate

WIA Rates

Examination of individual units showed the historical data of the combat troop WIA rates were represented by single and batch arrivals in a nonhomogeneous Poisson process. Representation of the 1,000 troop strength per day can be simulated with the use of a continuous distribution. These variates are exponentially distributed.

$$W \sim expo(\beta)$$

where:

β is the estimated mean.

A strong degree of autocorrelation also exists within each of the combat troop series. Specifying that any of the combat troops series data are independent is inappropriate. Generation of the series involves producing a stream of variates that possess the needed serial correlation. The series with autocorrelation is:

$$W_t = \alpha_1 + \alpha_2 W_{t-1} + \alpha_3 W_{t-2} + \alpha_3 W_{t-3} + \text{expo}(\beta)$$

where:

W_t = the WIA rate at time t.

α_t = constants used to develop the autocorrelation.

$\text{expo}(\beta)$ = the random number drawn from the computer.

The support troops and the extradivisional troops both have nonsignificant autocorrelation within each series, so a simple exponential distribution is used to generate these casualty events.

KIA Rates

The incidence of KIA is much lower than that of WIA, but it can be modeled in a similar fashion. As is the case with the WIA series, the KIA rates come from a nonhomogeneous Poisson process. Arrivals come in single and batch occurrences with interarrival rates represented by an exponential distribution. By aggregating into a 1000 strength per day system the model can be easily simulated with the use of a gamma distribution with varying parameters where:

$$K \sim G(\alpha, \beta)$$

and:

α is the shape parameter

β is the scale parameter

Analysis of the Model

Analysis of the casualty stream data generated by FORECAS is needed to ensure that the projection system accurately reflects the statistical trends evident in the empirical data. Because a feature of FORECAS is that it creates an ASCII data set which can be imported into any common statistical software program, serial and cross correlation tests may then be performed on the time series data. Each of the series is tested for autocorrelation, and the DNBI and WIA series are tested for cross correlation. Past research found that support rates are identically and independently distributed--consequently no autocorrelation should exist within each of these series and none was found. The combat series, however, possesses a degree of autocorrelation, which is shown by the following plots for the combat troop DNBI simulated series on the left and the actual historical data on the right.
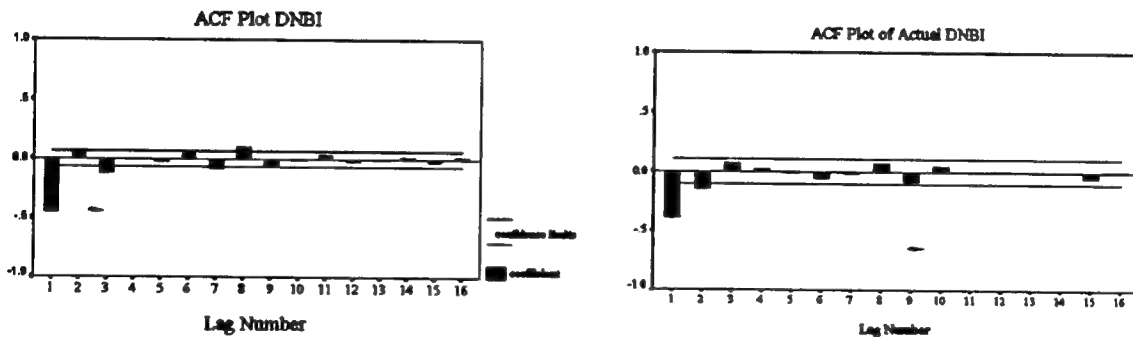

The first graph is the autocorrelation function (ACF) plot of the simulated data. This shows the extent of correlation within the time series. The second graph shows the ACF plot for the actual historical data. Both of these results are indicative of a time series with a moving average process of degree two[4].

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The same graphs are also used to compare the simulated combat troop WIA time series with the actual data.

ACF Plot WIA

ACF Plot of Actual WIA
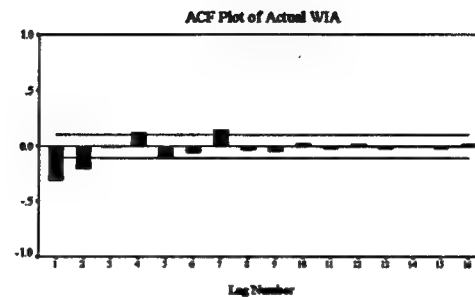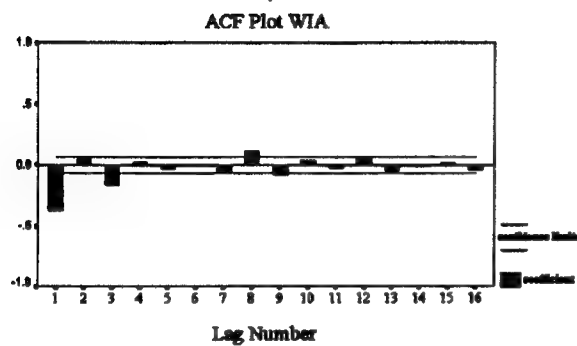
The graphs show that there is a significant degree of autocorrelation at the first day which decreases thereafter. These correlation plots show that the simulation results are similar to the historical data.

Cross-Correlation Function DNBI/WIA

Cross-Correlation Function of Actual DNBI/WIA
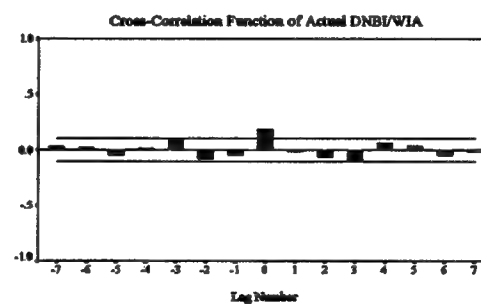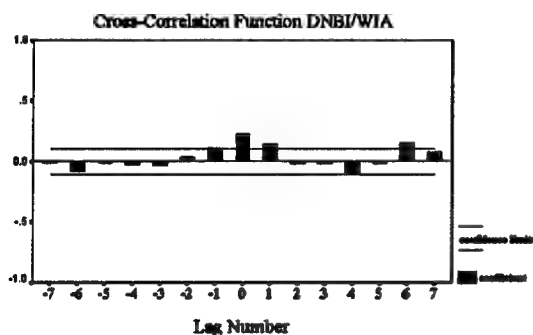
A test for cross-correlation between the DNBI and WIA series shows that there is a statistically significant finding at Day 0. A previous study has shown that there is a

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statistically significant correlation at Day 0[4]. These analyses indicate that the simulation accurately depicts the statistical patterns of empirical data and may be used to forecast casualty and illness arrivals during a hypothetical military scenario.

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A ground casualty projection system (FORECAS) has been developed to provide medical planners with estimates of expected daily arrivals of disease and non-battle injuries, wounded-in-action, and killed-in-action rates. Statistical characteristics of these rates are used as a basis from which the simulations are developed. By displaying the dispersion, range, and other statistical properties of casualty and illness data, FORECAS graphically depicts the potential patient flows within a theater of operations.

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